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Phase 2: Updated Geothermal Play Fairway Analysis of the Tularosa Basin, New Mexico

Greg Nash[1], Adam Brandt[1], Brian Pfaff[1], Christian Hardwick[2], Mark Gwynn[2], Kelly[3] Blake, Stuart Simmons[1], Carlon Bennett[4]

[1]Energy and Geoscience Institute at the University of Utah, [2]Utah Geological Survey, Navy [3]Geothermal Program Office, [4]Ruby Mountain, Inc.

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ABSTRACT

Play fairway analysis (PFA) methodologies, both deterministic and stochastic, are being applied for medium to low enthalpy geothermal resources in the Tularosa Basin, in south-central New Mexico. These PFA methods use datasets representative of heat, groundwater and fault-fracture related permeability to locate areas with the lowest risk of geothermal energy development. Our Phase 1 PFAs predicted several plays throughout the study area, with a range of certainty and risk, based upon legacy data. In Phase 2, new data were collected for high priority plays and integrated into the PFAs to enhance certainty and further reduce risk. Field geology, gravity surveys and alluvial fan geomorphology supplemented the understanding of geologic structure and potential permeability, while additional well sampling, geothermometry and temperature logging provided valuable information about heat in the subsurface. In order to statistically compare and contrast the layers of evidence in the Tularosa Basin with the broader Great Basin, a probabilistic Weights of Evidence analysis was conducted in parallel with the inclusive and deterministic petroleum industry logic PFA. Both methods yielded 3 similar plays, while Weights of Evidence identified 2 additional plays. A sixth play was inferred around the NASA-Aerospace Data Facility Southwest site, north-east of Las Cruces, based on a promising shallow temperature survey, geothermometers, and structural interpretations of geophysical data. The White Sands Missile Range main cantonment (headquarters) play is now given high priority, along with McGregor Range, Fort Bliss, due to the discovery of relatively high geothermometer values.

1. Introduction

The Tularosa Basin is a graben located in the southern Rio Grande Rift (Fig. 1). The study area covers approximately 7700 miles^2, most of which is underexplored. Several factors went into the selection of the Tularosa Basin. It was primarily chosen because it is a challenging, yet ideal test bed to evaluate effectiveness of PFA.

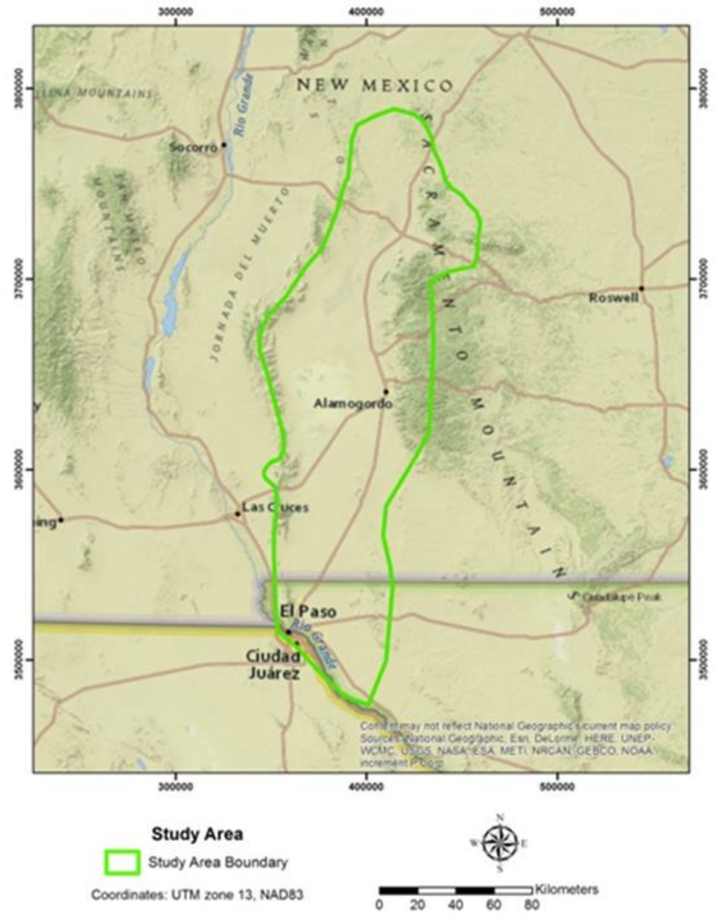


Figure 1: Map of the study area in south-central New Mexico, USA.

Additionally, Tularosa Basin is home to several military installations including White Sands Missile Range and Fort Bliss, which are the first and second largest U.S. Army bases in the United States, together covering more than 10,000 km^2 of southeastern New Mexico. The much smaller Holloman Air Force Base also lies within the study area. Geothermal development in this area could help the military achieve its Net Zero Energy goals.

Our Phase 1 PFA used a deterministic method based upon petroleum industry logic (Fraser et al., 2001) and the probabilistic Weights of Evidence (WoE) method (Sawatzky et al, 2009; Coolbaugh, 2003; Bonham-Carter, 1994). The models were based upon (1) heat of the Earth, (2) fault related permeability, and (3) ground water. The heat and water data used in these models was collected from public databases, local governments, and literature. Upon exhausting these sources, enough data was present to create the PFAs, although significant expanses of the study area were data poor or lacking data. Phase 1 PFA analyses identified 12 plays (Fig. 2). The plays were then prioritized based upon economic analyses, land status, and proximity to transmission lines.

2. Deterministic Play Fairway Analysis: Petroleum Logic Approach

Petroleum Industry PFA logic involves using three composite risk segments (CRS) that represent the three primary aspects of a petroleum system. Meeting the needs of a geothermal system

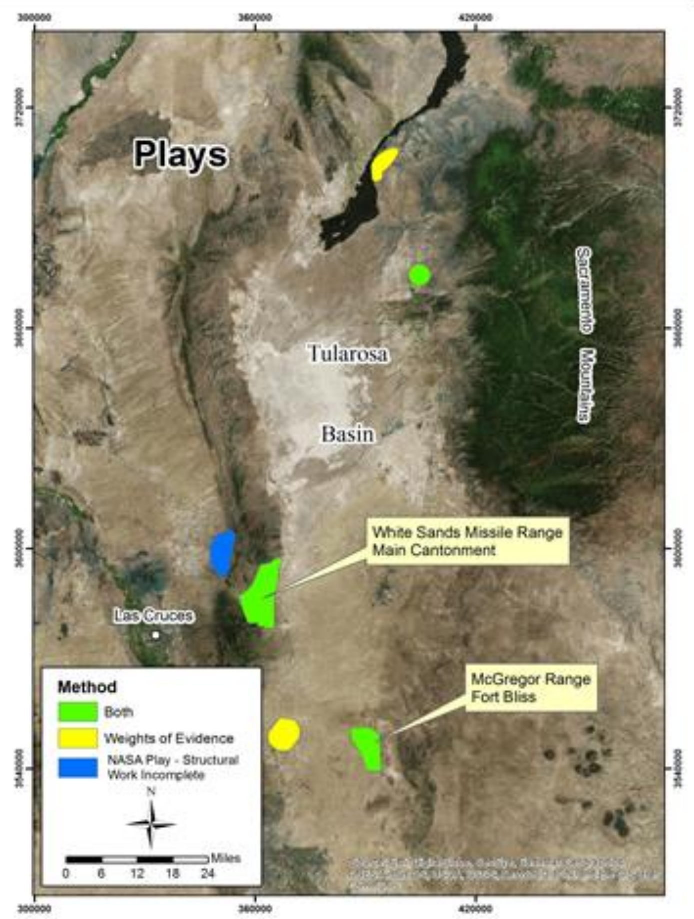


Figure 2: Phase 1 plays and the methods used to identify them.

requires redefining CRS layers as heat, permeability and ground water. Each CRS was a fusion of thematically related statistical surfaces derived from point source data. Individual statistical surfaces were created using the inverse distance weighted (IDW) method in ArcGIS. The interpolated data were then classified into (1) Low Risk, (2) Moderate Risk, and (3) High Risk and vectorized. The Low Risk classification was based on values associated with known geothermal systems in the Great Basin. The Moderate Risk classification was based upon the range between the upper end of the Low Risk class and values that should represent entry into deep direct use applications. The High Risk classification included all other values. The three final vector datasets were then fused using the Union Overlay technique in ArcGIS to create the heat of the Earth CRS. This retained the data from all three input datasets in an associated table. The CRS's were then fused to produce the final version of this PFA.

2.1 Heat of the Earth CRS

The methods used in Phase 2 closely follow those used in our Phase 1 PFA, with the notable exception that in Phase 1 the 2011 SMU Geothermal Laboratory Heat Flow Map of the Coterminous United States (Blackwell et al., 2011) was used for heat flow. For Phase 2, this data was thought to be overly generalized due to the small scale of the map. Therefore, the SMU

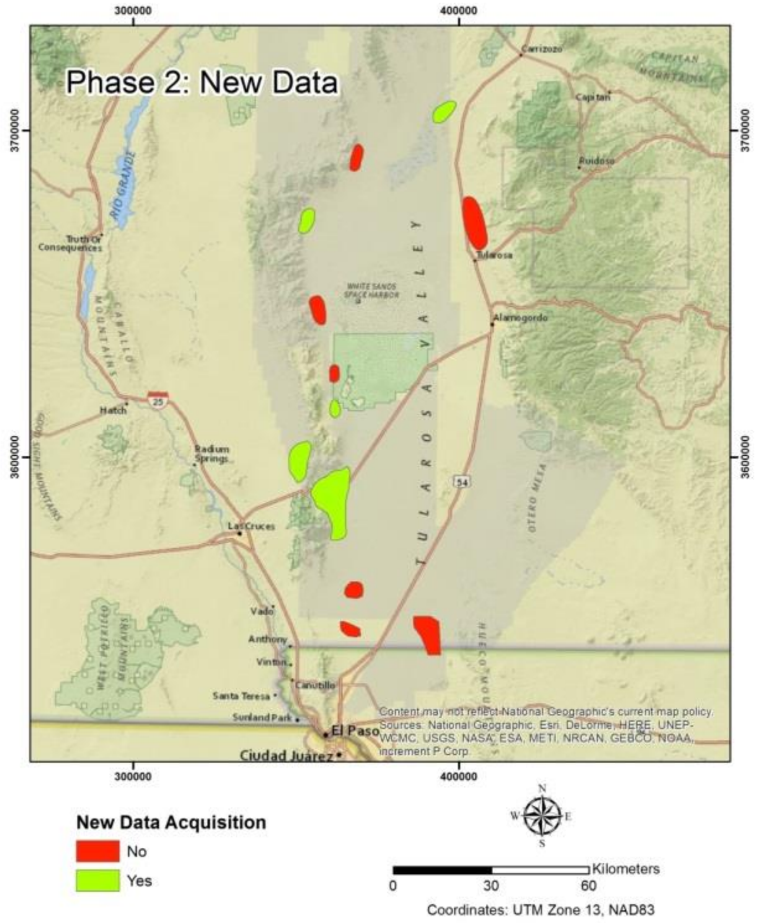
Geothermal Laboratory heat flow data were re-interpolated over the study area. Additionally, new quartz geothermometers and temperature gradient data, acquired during Phase 2 (Fig. 3), were added to Phase 1 datasets which were re-interpolated. The resultant raster grids were then classified as follows and vectorized as discussed in detail in our Phase 1 report.

Temperature gradients (Fig. 4): 0 ºC/km – 60 ºC/km = High Risk; 60 ºC/km – 80 ºC/km = Medium Risk; >80 ºC/km = Low Risk.

Quartz Geothermometer (Fig. 5): 0 ºC – 60 ºC = High Risk; 60 ºC – 80 ºC = Medium Risk; >80 ºC = Low Risk.

Heat flow was digitized as vector data directly from the SMU 2011 heat flow map (Blackwell et al., 2011). It was classified as follows (mW/m^2): 55 – 70 = High Risk; 70 – 85 = Medium Risk >85 = Low Risk.

The final heat CRS was then created through the fusion of the three heat vector layers. The results can be observed on Figure 4.



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Coordinates: UTM Zone 13, NAD83

Figure 3: Phase 1 plays where new data, representing heat of the Earth, were acquired for Phase 2.

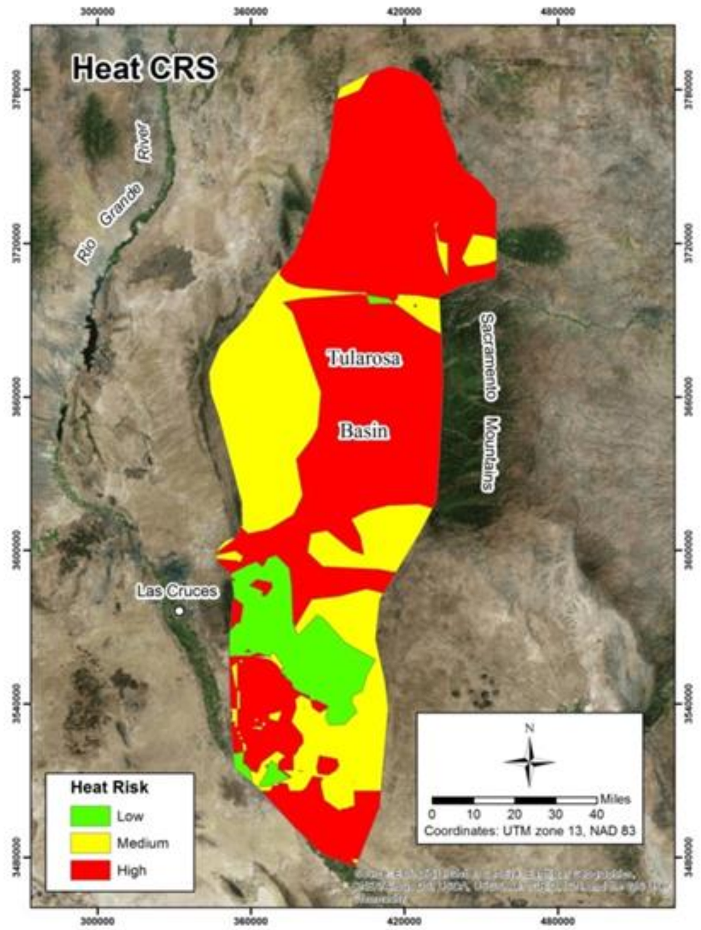

Figure 4: Heat CRS -- fusion of heat flow, temperature gradient, and quartz conditional geothermometer data.

2.2 Fracture Permeability CRS

This CRS was developed using Quaternary faults and zones of critical stress (Faulds et al., 2006, 2010, 2013). Quaternary faults, derived from the USGS Quaternary Fault and Fold Database of the United States, were clipped to fit the study area and then buffered at a distance of 1 km (Fig. 5). The resultant polygons were then all classified as Medium Risk, not Low Risk, because fault movement can open new permeability, but it can also close fractures.

Zones of critical stress form in structural settings such as fault step-overs, terminations, apexes, intersections, and accommodation zones. Critical stress zones were mapped using analysis of aerial photography, Bouguer gravity, and total magnetic data. Each zone was considered to be encompassed within a 5 km diameter buffer, except where evidence indicated that a larger area may be impacted. Resultant polygons were classified as Low Risk (Fig. 5).

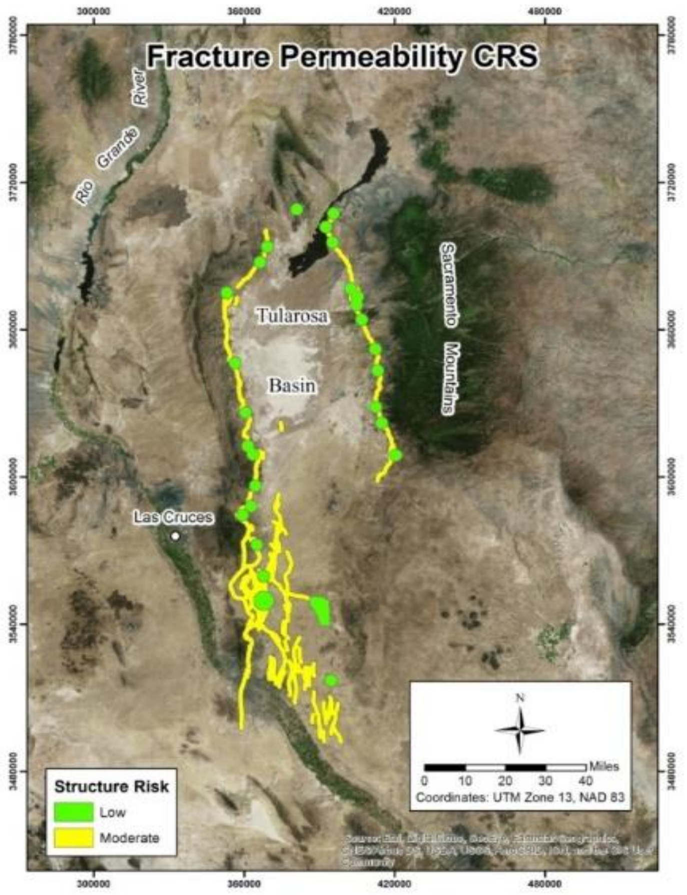

Figure 5: Fracture permeability CRS: Quaternary faults @ 1 km buffer (each side of fault) and 5 km diameter zones of critical stress.

2.3 Ground Water

Ground water appears to be well distributed in the Tularosa Basin based upon producing wells (New Mexico Office of the State Engineer – POD waters). Additionally, Pleistocene Lake Otero occupied the west central part of the basin providing deep aquifer recharge and water wells not found in the POD database are distributed at White Sands Missile Range (WSMR) and NASA-ADFSW. It was found during Phase 1 that water was of little consequence in the PFA due to its availability. Therefore, the Phase 2 deterministic PFA did not use a ground water CRS.

2.4 Final Petroleum Industry Logic PFA

The final deterministic PFA was created through an overlay of the heat of the Earth and fracture permeability CRS layers (Fig. 6). This PFA contains 7 plays, whereas the Phase 1 PFA deterministic model that produced 8 plays. This was due to the re-interpolation of heat flow data, which eliminated some broadly interpolated high heat flow areas in the west-central and northwestern part of the basin.

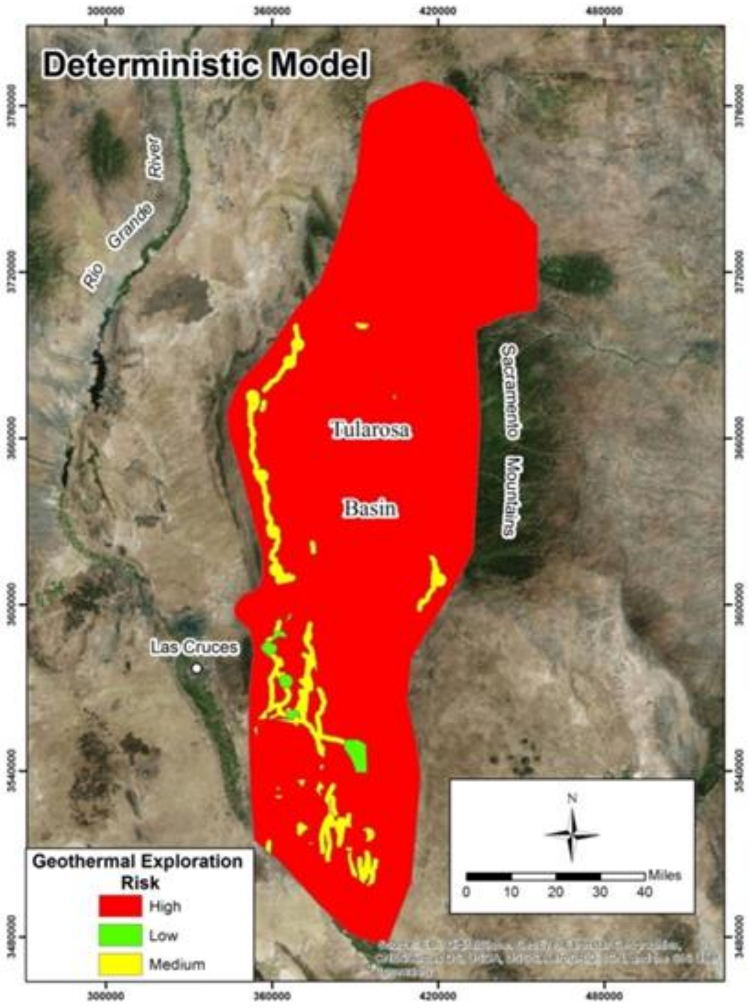

Figure 6: Deterministic petroleum industry logic PFA model showing seven low risk areas.

2.4.1 Certainty

Certainty has many factors including data quality and spatial distribution. Because all of the data used in Phase 1, which also constitutes the majority of data used for Phase 2, came from public databases and literature, we can only assume that it is of high quality. The newly acquired data used in Phase 2 modeling were collected using best known industry practices.

Spatial distribution is critical due to inherent error which propagates between widely spaced data points during interpolation. Therefore, data points were buffered at a 5 km radius with the results being incorporated into the model to show areas of no data, which are low certainty (Fig. 7). This reduced the number of plays to six through the elimination of a play which was based solely upon interpolation. Simple kriging probability was also used at a threshold of 80% for certainty as follows: 0.0-0.6 = low certainty, 0.6-0.8 = medium certainty, and 0.8-1.0 = high certainty using heat CRS input data (Fig. 8). Only three plays fell into the high certainty category. The availability of water was also considered, although not as an input CRS, through an overlay shown in Figure 9, which shows water within all low risk areas.

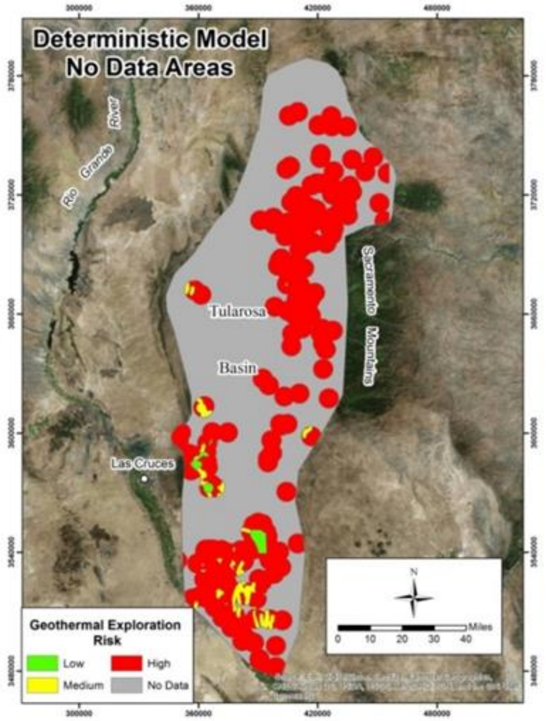

Figure 7: Areas of no data (gray) in relation to PFA results.

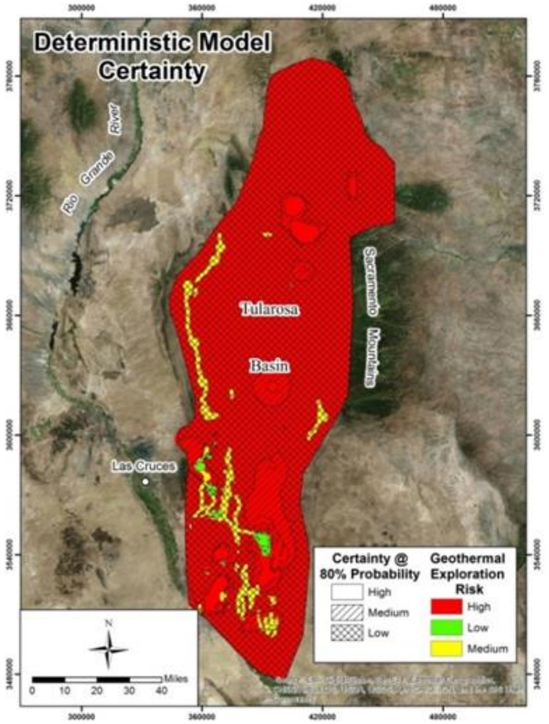

Figure 8: Certainty based on a 0.8 cutoff on CRS Input simple kriging probability models.

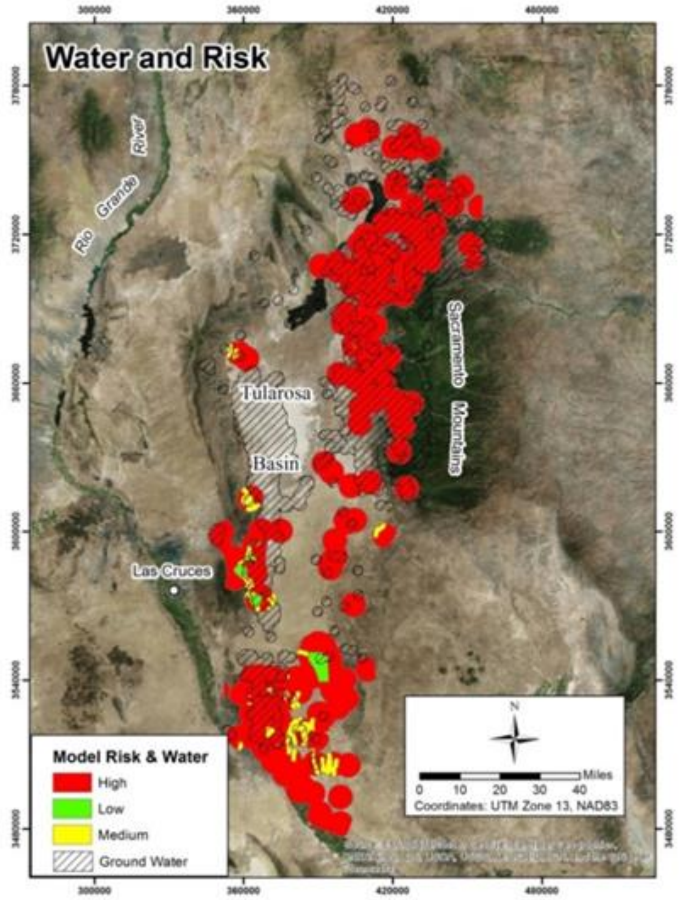

Figure 9: PFA with no data zones removed and the water resource layer added. Water is available for all low risk areas.

3. Probabilistic Play Fairway Analysis: Weights of Evidence Approach

The Weights of Evidence method used for the Phase 1 was again applied to the revised Phase 2 data. The use of this technique was based on work done by Moghaddam et al, (2013), where they found it to be the superior stochastic method, out of several tested, for geothermal exploration model development. This technique examines multiple layers of evidence, which makes it ideal for this work. It first calculates weights for each evidential layer based upon the spatial relationships of training points, which are located at known geothermal systems and hot springs, and then produces a posterior probability raster surface, a certainty raster surface, and other related statistics.

A problem applying this method was encountered for the Tularosa Basin where a lack of training sites existed. There is only one partially proven geothermal system in the area and no hot springs exist. This was addressed by creating regional statistical surfaces, for training use, that covered Nevada, Utah, and New Mexico. This gave access to ample training sites. Spatial Data Modeler was used for the WoE analysis (Sawatzky et al, 2009)

3.1 WoE Layers of Evidence

In Phase 1, water chemistry data, from the Great Basin Groundwater Geochemical Database from the Nevada Bureau of Mining and Geology (http://www.nbmg.unr.edu/Geothermal/GeochemDatabase.html) and additional data from the Oregon Institute of Technology Geo-Heat Center (http://www.oit.edu/orec/geo-heat-center), were compiled into an ArcGIS shapefile. Redundant points were removed and the quartz (conductive) geothermometer (Fournier, 1991) calculated. The IDW interpolation method was then applied to the quartz geothermometers using ArcGIS to create a regional raster statistical surface. The same process was also applied to heat flow and temperature gradient data originating from the SMU Geothermal Laboratory (http://www.smu.edu/dedman/academics/programs/geothermallab). Extrapolation was allowed into areas with no data for the evidential layers. However, training sites were only chosen in data rich areas where the statistical surfaces were very accurate.

For Phase 2, raster IDW statistical surfaces, specific to the Tularosa Basin project area, created for the deterministic model using newly acquired data as well as data collected during Phase 1, were integrated onto the regional surfaces discussed above to update them (Fig. 8). The datasets were then classified, using standard deviations of the mean, to: Heat Flow = 16 classes, Temperature Gradients = 12 classes and Quartz Geothermometers = 13 classes).

Fault related fracture permeability was represented by zones of critical stress (Fig. 9). These originated from Faulds Structural Inventory of Great Basin Geothermal Systems and Definition of Favorable Structural Settings (http://en.openei.org/datasets/dataset/structural-inventory-of-great-basin-geothermal-systems-and-definition-of-favorable-structural-setti2) in Nevada and Utah and were mapped by the PI in New Mexico. This data was considered to be binary (critical stress zone = 1, all other areas = 0) as layers of evidence. Training points are shown in Figure 10. Ground water was not used as a layer of evidence for the same reason given in the deterministic model section earlier in this report.

The final WoE post probability model overlain with the confidence layer is shown in Figure 11. It was not anticipated that high probabilities would be produced for the Tularosa Basin due to the placement of training points at known systems that were generally high enthalpy and this was the case. McGregor Range at Fort Bliss, the only know geothermal system in the area, had the highest probability within the study area at 0.047.

4. Final Plays

Plays from the deterministic model were chosen primarily on being located in low risk areas. Plays from the WoE model were chosen primarily on having probability values that were greater than background. Certainty was then considered and a play had to have high certainty either from (1) kriging probability or (2) WoE confidence. Finally, each play had to be at least partially within a 5km diameter radius of a data point. The final play map can be seen in Figure 12.

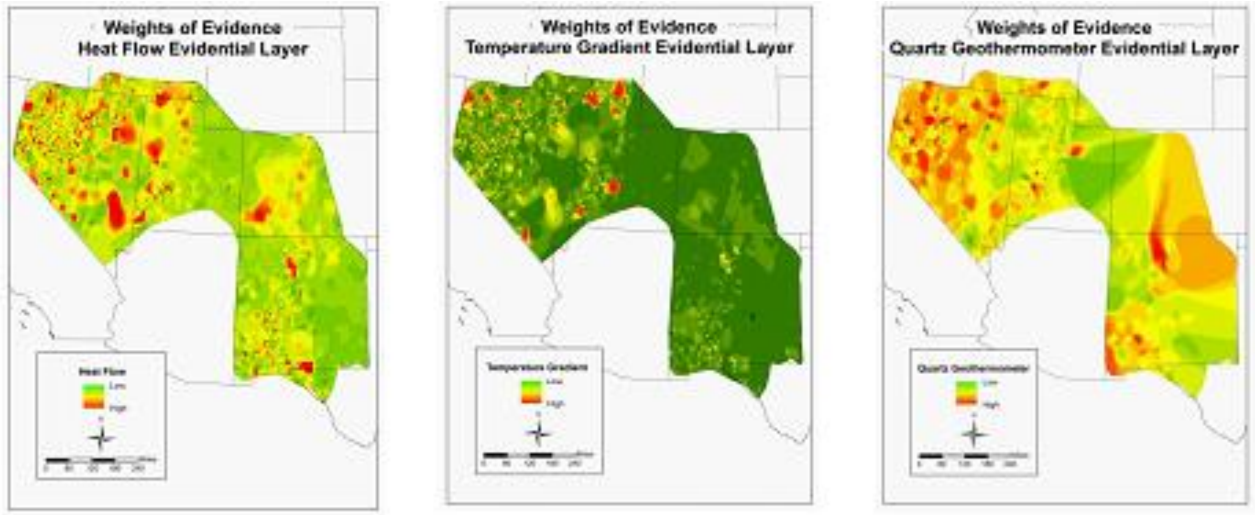

Figure 8: Evidential layers for heat. Please note that no data were used for eastern Utah or Colorado so data covering these areas are interpolations. Training points were located in data rich areas in Nevada, New Mexico, and Utah.

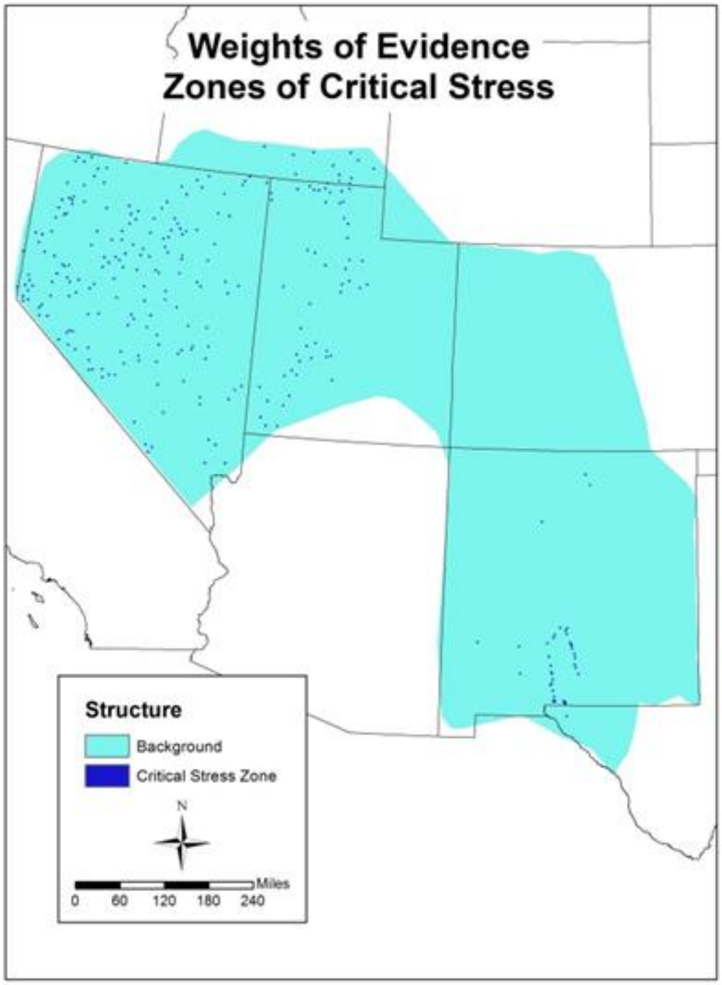

Figure 9: Zones of critical stress layer of evidence.

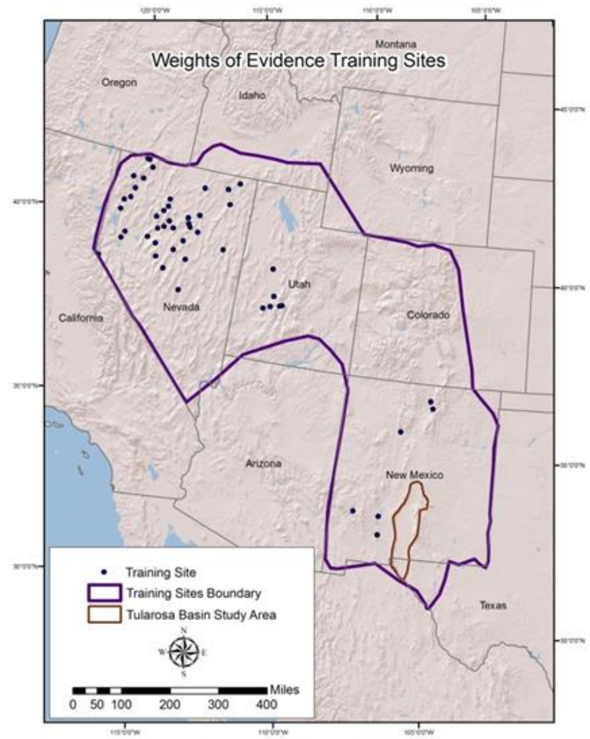

Figure 10: Training points used in WoE analysis.

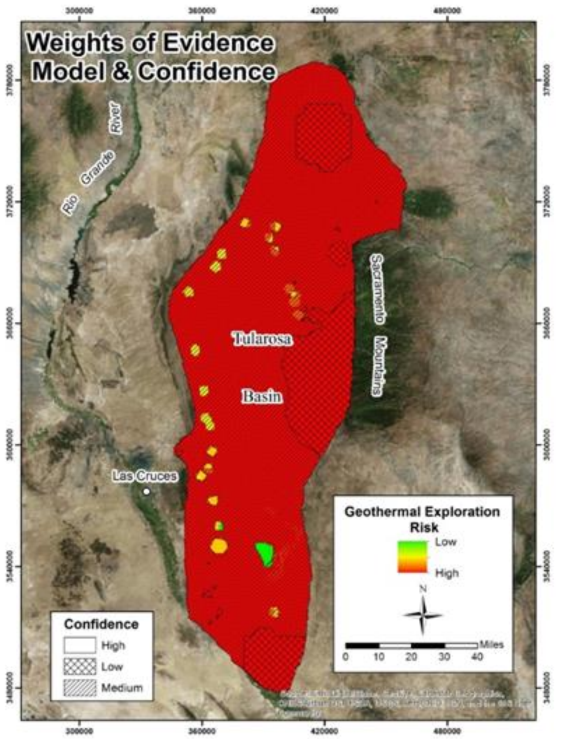

Figure 11: WoE post probability model overlain with the WoE confidence layer. All red areas had 0.0 probability. McGregor Range at Fort Bliss had the highest probability in the study area. It too, however, has the most available data.

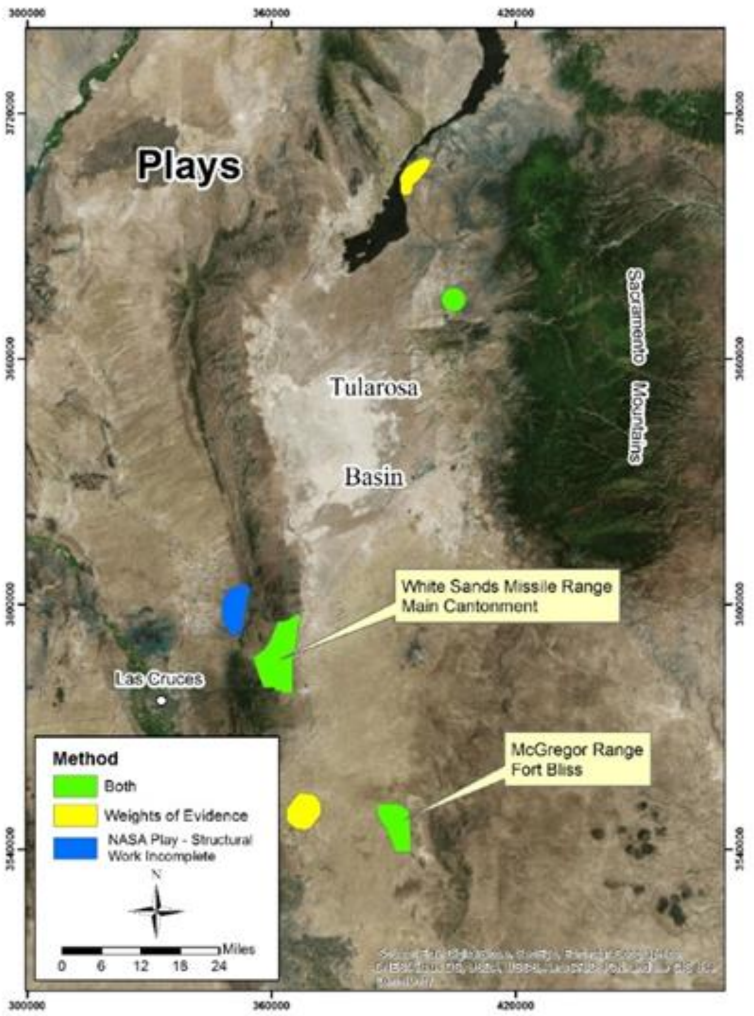

Figure 12: Final Phase 2 play map showing the methods used to predict the plays. Most of the plays were predicted by both methods.

Phase 2 resulted in a significantly reduced number of plays from those produced in Phase 1 (Fig. 13). This was due to the re-interpolation of heat flow data as previously mentioned, which resulted in lower values over part of the study area, and because of the application of certainty and areas of no data were more conservative. Additionally, the plays were prioritized (Fig. 14) as follows: (1) if both PFA methods indicated the presence of a play and all methods of certainty were high the play was considered high priority; (2) if both PFA methods indicated the presence of a play an only a single method of certainty was high, the play was considered medium priority; and (3) if a single PFA method indicated the presence of a play and a single method indicated high certainty the play was ranked as low priority. This leaves the McGregor Range and WSMR Main Cantonment plays as the highest priorities.

The NASA-ADFSW play (colored blue on Figs. 13 & 14) was in the low risk category on the deterministic heat CRS, however, structural interpretation is still underway for this area so no zone of critical stress has yet been mapped. This work at this play was funded by the U. S. Air

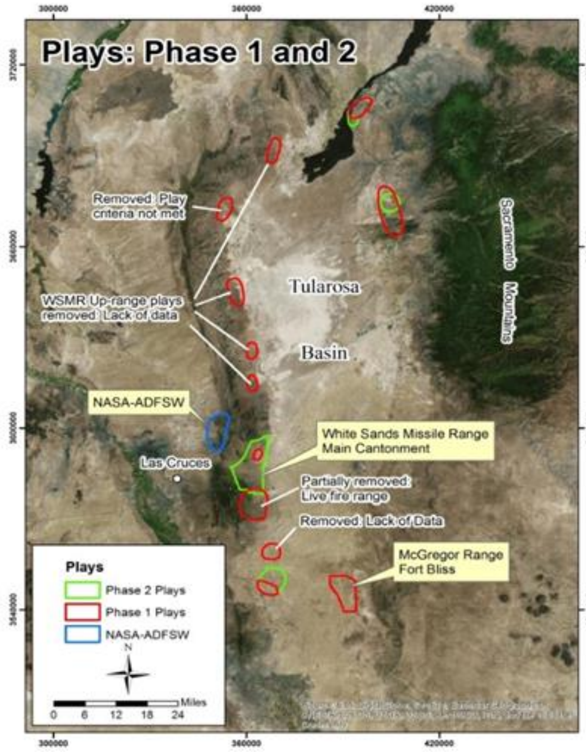

Figure 13: Play comparison between Phase 1 and 2.

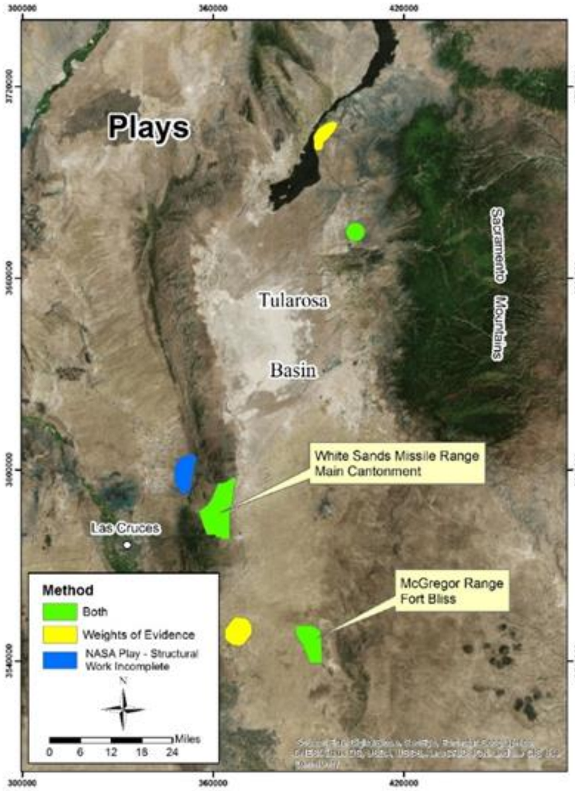

Figure 14: Phase 2 play prioritization.

Force. It is anticipated that additional data will become available to complete this work. If a zone of critical stress can be confirmed, it will become a PFA play.

5. Conclusions

The number of plays predicted in Phase 2 was reduced from those predicted in Phase 1 due to a more restrictive heat flow dataset and a more conservative application of certainty. The remaining plays, however, were predicted both in Phase 1 and Phase 2. The McGregor and WSMR plays are the top priority plays and, if additional data acquisition supports heat and fault related permeability at NASA-ADFSW, it too will become a high priority play. These plays all lie on military land in very close proximity to facilities that would benefit from geothermal power production. It is anticipated that Phase 3 work, including the drilling of 1000' deep temperature gradient holes in strategic locations and additional geophysical work, will lead to the siting of production wells on these plays. Lower priority plays would benefit from additional data acquisition in the future.

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